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THE INFLUENCE OF TEMPERATURE AND MOONLIGHT ON FLIGHT ACTIVITY OF *CULICOIDES VARIIPENNIS* (COQUILLETT) (DIPTERA: CERATOPOGONIDAE) IN NORTHERN CALIFORNIA

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Abstract.—Catches of female *Culicoides variipennis* (Coquillett) in CO_2-baited and nonbaited CDC-miniature light traps in Northern California revealed two main peaks of flight activity. As long as temperature remained within acceptable limits (approx. 7° C to 29° C), there was a major peak near sunset and a secondary one near dawn. When temperatures were favorable for flight, gnats were caught throughout the night on moonlit nights. On moonless nights, very few gnats were collected after the second hour following sunset. In western Sonoma County, low nighttime temperatures (< 12–13° C) usually curtailed, or greatly reduced, nocturnal and dawn flight activity. In the northern San Joaquin Valley (Stanislaus County), however, temperature did not play a significant role in regulating overnight flight activity since it remained above 13° C all night long on collection dates.

Key Words.—Insecta, Diptera, Ceratopogonidae, *Culicoides variipennis,* flight activity, temperature, light

It is well known that many insects exhibit crepuscular and nocturnal flight activity, and this appears to be true for *Culicoides variipennis* (Coquillett). The few studies of *C. variipennis* flight activity have found that the main period of flight (aerial dispersal) is near dusk, with a second smaller peak near dawn (Barnard & Jones 1980, Nelson & Bellamy 1971). Although such a bimodal pattern was usual, these workers reported that other factors, such as temperature and moonlight, could alter this flight pattern. This study determined the pattern of flight activity of *C. variipennis* in northern California, and the possible influence of temperature and moonlight upon it.

Materials and Methods

In 1983, the study was conducted at a dairy in western Sonoma County (approximately 15 km NW of Santa Rosa). A description of the trapping site as well as the trap types and the basic trapping design have been described by Anderson & Linhares (1989). Overnight trapping was conducted on the following dates: 16–17, 30 Jun; 1, 7–8, 28–29 Jul; 12–13, 25–26 Aug; 9–10, 16–17, 19–20 Sep.

On each date, trapping of adults started two hours before sunset and lasted until one hour after sunrise on the following morning, for a total of 10 trapping periods (Tables 1, 2). Traps were checked at one h intervals for the first five h (or until three h after sunset) and for the last two h of collection (or from one h before to one h after sunrise). Collection bags were changed if gnats were present. The remainder of the period (from three h after sunset until one h before sunrise) was

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Table 1(a). Nightly collections of *Culicoides variipennis* females on dates of different moon phases in western Sonoma County, 1983. Table subsections: (a) 16–17 Jun, 30 Jun–1 Jul; (b) 7–8, 28–29 Jul; (c) 12–13, 25–26 Aug; (d) 9–10, 16–17 Sep; (e) 19–20 Sep.

	16–17 Jun					30 Jun–1 Jul				
Trapping period[a]	Number collected	Proportion of total	Moon[b]	Air temp. (°C)	R.H. (%)	Number collected	Proportion of total	Moon	Air temp. (°C)	R.H. (%)
1	12	0.03	0	22.8	52	5	0.04	0	26.7	45
2	87	0.23	0	18.9	63	4	0.03	0	24.4	53
3	191	0.50	0/+	14.4	76	32	0.26	0/−	19.4	69
4	76	0.19	+	13.3	85	36	0.29	−	16.7	94
5	15	0.04	+	11.7	94	4	0.03	−	15.6	98
6	3	0.01	+	8.3	100	16	0.13	+	14.4	100
7	0	0.0	−	7.2	100	6	0.05	+	13.9	100
8	0	0.0	−	6.7	100	12	0.1	+	12.8	100
9	0	0.0	−/0	6.1	100	9	0.07	+/0	11.7	100
10	0	0.0	0	8.3	100	0	0	0	11.1	100
Total collected	384					124				

[a] Sunset occurred at the beginning of period 3 and sunrise occurred at the beginning of period 9.
[b] The presence or absence of moonlight is indicated respectively by the signs (+) and (−). During periods 1, 2 and 10, the presence of sunlight (0) was significant and, therefore, the presence or absence of moonlight was not considered a factor. Because of the persistence of indirect sunlight, periods 3 and 9 had about 30 min of measurable light, in addition to either 30 min of darkness or moonlight. Period 4 on 28–29 Jul was transitional from darkness to moonlight.

divided into three periods of equal duration and all traps were checked at the end of each period.

The time of sunset and sunrise for each trapping day was determined from annual issues of the American Ephemeris and Nautical Almanac (U.S. Government Printing Office, Washington, D.C.). Temperature, relative humidity, wind velocity and direction and the presence or absence of moonlight were recorded at half-hour intervals for the first five and the last two h of collection, and at the beginning of the remaining three night periods. Changing light intensities during periods 3 and 9 were measured with a Weston light meter directly exposed to the

Table 1(b). (cont.)

	7–8 Jul					28–29 Jul				
Trapping period[a]	Number collected	Proportion of total	Moon	Air temp. (°C)	R.H. (%)	Number collected	Proportion of total	Moon	Air temp. (°C)	R.H. (%)
1	10	0.07	0	21.1	55	14	0.04	0	25	56
2	39	0.26	0	19.4	70	74	0.19	0	22.2	60
3	77	0.51	0/−	17.2	82	119	0.31	0/−	19.4	68
4	17	0.11	−	15	93	110	0.29	−/+	16.7	82
5	5	0.03	−	13.3	100	28	0.07	+	13.9	91
6	1	0.01	−	11.7	100	18	0.05	+	12.2	99
7	2	0.01	−	7.8	100	4	0.01	+	10.6	100
8	0	0	+	6.1	100	3	0.01	+	8.9	100
9	0	0	+/0	5.6	100	1	0	+/0	8.3	100
10	0	0	0	5.6	100	12	0.03	0	10	100
Total collected	151					383				

Table 1(c). (cont.)

	12–13 Aug					25–26 Aug				
Trapping period[a]	Number collected	Proportion of total	Moon	Air temp. (°C)	R.H. (%)	Number collected	Proportion of total	Moon	Air temp. (°C)	R.H. (%)
1	5	0.03	0	21.7	63	32	0.12	0	23.9	60
2	9	0.05	0	17.2	70	172	0.62	0	19.4	70
3	81	0.47	0/+	14.4	84	24	0.09	0/+	14.4	91
4	42	0.24	+	13.3	97	26	0.09	+	12.8	96
5	29	0.17	+	11.1	100	14	0.05	+	10.6	100
6	0	0.0	–	11.1	100	9	0.03	+	8.9	100
7	0	0.0	–	11.1	100	0	0.0	+	8.3	100
8	0	0.0	–	11.1	100	0	0.0	+	7.2	100
9	0	0.0	–/0	11.1	100	0	0.0	+/0	5.6	100
10	7	0.04	0	11.1	100	0	0.0	0	8.9	100
Total collected	173					277				

sky at about 1 m above ground level. Any other meteorological conditions such as cloud cover and rain also were recorded.

Preliminary results for 1983 indicated low flight activity at night, even when moonlight was present. As this seemed related to temperatures on most of the collecting nights, overnight collections in 1984 were made in a warmer area (northern San Joaquin Valley of California). The 1984 study was conducted at a large dairy in Stanislaus County, approximately 3 km WNW of Turlock Lake State Park. The traps and the trapping design used were the same as in 1983.

During 1984, trapping was conducted along a fence line in the vicinity of a bullpen and a corral where several calves were kept. Overnight collections coinciding with full moon periods were made on: 9–10, 11–12, 13–14 Jul; 9–10, 13–14 Aug. Throughout each trapping period, temperature and relative humidity were continuously recorded with a hygrothermograph. Other meteorological conditions were recorded as in 1983.

All files collected in both years were identified, sexed and counted.

To assess the possible influence of moonlight and temperature on flight activity,

Table 1(d). (cont.)

	9–10 Sep					16–17 Sep				
Trapping period[a]	Number collected	Proportion of total	Moon	Air temp. (°C)	R.H. (%)	Number collected	Proportion of total	Moon	Air temp. (°C)	R.H. (%)
1	9	0.03	0	25	38	10	0.02	0	18.9	63
2	123	0.37	0	20.6	51	21	0.04	0	15.6	75
3	146	0.44	0/–	13.9	87	88	0.18	0/+	11.7	93
4	54	0.16	–	11.1	100	24	0.05	+	10	98
5	0	0.0	–	10	100	8	0.02	+	9.4	100
6	0	0.0	–	8.3	100	13	0.03	+	10	100
7	0	0.0	–	6.1	100	0	0.0	–	10.5	100
8	0	0.0	–	5.0	100	0	0.0	–	10.5	100
9	0	0.0	–/0	3.8	100	35	0.07	–/0	10.5	100
10	0	0.0	0	6.1	100	282	0.59	0	10.5	100
Total collected	332					481				

Table 1(e). (cont.)

	9–10 Sep				
Trapping period[a]	Number collected	Proportion of total	Moon	Air temp. (°C)	R.H. (%)
1	24	0.02	0	26.7	45
2	190	0.15	0	21.1	47
3	593	0.47	0/+	15.6	79
4	286	0.22	+	11.1	100
5	143	0.11	+	9.4	100
6	30	0.02	+	7.8	100
7	6	0.01	+	7.2	100
8	0	0.0	+	6.1	100
9	0	0.0	+/0	3.3	100
10	0	0.0	0	4.4	100
Total collected	1272				

as measured by trap catches, an analysis of variance was performed using the SAS® GLM procedure (SAS 1985). The dependent variable was defined as Log (P + 1), where P was the proportion of the total catch in each of the collecting periods for each trapping date. The temperature, presence or absence of moonlight and trapping periods were considered factors in the analysis. Periods 3 and 9 usually were transitional between dim, indirect sunlight and either moonlight or darkness, but they were included in the analysis because the latter conditions persisted for at least half of these periods.

Results and Discussion

Tables 1 and 2 present the trapping results for 1983 and 1984. Nightly trap catch patterns for 1983, as percentages of the total catch per night, reveal a strong influence of temperature upon flight activity in the Santa Rosa region. Here, temperatures dropped below 10° C for several periods during most collecting nights, even though daytime temperatures were often above 25° C. The analysis of variance showed a statistically significant correlation between the presence of moonlight and greater flight activity, as measured by light trap catches ($F = 6.79$, $P < 0.0139$, $df = 1$). However, during several periods when bright moonlight was present but the temperature was low, no gnats were caught. Obviously, temperature also greatly influenced flight activity in the periods after sunset as evidenced by trap catches and by the results of the analysis of variance ($F = 5.35$, $P = 0.0001$, $df = 26$). No flight occurred below 7.2° C. Temperatures below 12–13° C usually greatly suppressed nocturnal flight activity in the Santa Rosa area (Table 1), and temperatures below 17° C usually greatly suppressed nocturnal flight activity in the San Joaquin Valley (Table 2). The warmer daytime temperatures (27–37° C) in the San Joaquin Valley affected the flight activity of *C. variipennis* by delaying the onset of flight activity and by delaying the evening peak.

The period of greatest flight activity occurred around sunset (Tables 1, 2; Figs. 1–3). When temperature permitted, smaller peaks of flight activity also were observed near dawn, particularly on nights when the temperature remained above 10° C (Tables 1, 2; Fig. 3). Also, when temperature permitted, gnats were collected all night long in the presence of moonlight (Tables 1, 2; Figs. 2, 3). Thus, the

Table 2(a). Nightly collections of *Culicoides variipennis* females on dates of full moon in the San Joaquin Valley of California (Stanislaus County), 1984. Table subsections: (a) 9–10, 11–12 Jul; (b) 13–14 Jul, 9–10 Aug; (c) 13–14 Aug.

	9–10 Jul					11–12 Jul				
Trapping period[a]	Number collected	Proportion of total	Moon	Air temp. (°C)	R.H. (%)	Number collected	Proportion of total	Moon	Air temp. (°C)	R.H. (%)
1	64	0.01	0	32.2	35	70	0.01	0	35	28
2	542	0.08	0	27.2	43	403	0.03	0	28.9	35
3	1295	0.19	0/+	22.2	60	4489	0.36	0/+	26	49
4	1608	0.23	+	21.1	72	1976	0.16	+	22.2	51
5	1060	0.15	+	18.9	68	1003	0.08	+	21.1	54
6	1264	0.18	+	17.2	73	1563	0.13	+	20	57
7	288	0.04	+	14.4	86	1365	0.11	+	18.9	70
8	100	0.01	–	11.1	100	622	0.05	+	16.1	85
9	107	0.02	–/0	10.6	100	460	0.04	+/0	15	100
10	633	0.09	0	15.6	88	454	0.04	0	20	86
Total collected	6961					12,405				

[a] Sunset occurred at the beginning of period 3 and sunrise occurred at the beginning of period 9.
[b] The presence or absence of moonlight is indicated respectively by the signs (+) and (–). During periods 1, 2 and 10, the presence of sunlight (0) was significant and, therefore, the presence or absence of moonlight was not considered a factor. Because of the persistence of indirect sunlight, periods 3 and 9 had about 30 min of measurable light, in addition to either 30 min of darkness or moonlight.

presence of moonlight had a positive influence upon flight activity. In the absence of moonlight few *C. variipennis* females were collected after the fourth trapping period (the second one-h trapping period after sunset). Periods 3 and 9 were transitional periods during which there was a maximum of 30 min of indirect, measurable light (about 1–2 foot candles) following sunset or preceding sunrise.

Wind was not a factor of decisive influence during overnight trapping. Although winds up to 13 km/h occasionally were recorded during the first two or three h of collection, wind velocity usually decreased in intensity and was not present after the fourth h, except for an occasional unmeasurable breeze.

The possible influence of cloud cover could not be assessed because for most

Table 2(b). (cont.)

	13–14 Jul					9–10 Aug				
Trapping period[a]	Number collected	Proportion of total	Moon	Air temp. (°C)	R.H. (%)	Number collected	Proportion of total	Moon	Air temp. (°C)	R.H. (%)
1	18	0.0	0	37.8	28	132	0.01	0	35.6	25
2	638	0.04	0	31.7	42	932	0.05	0	28.9	35
3	4212	0.25	0/+	28.9	50	6803	0.34	0/+	24.4	48
4	2689	0.16	+	26.7	57	4065	0.20	+	23.9	54
5	1407	0.08	+	25.6	62	2229	0.11	+	21.1	62
6	2320	0.14	+	25.6	60	2942	0.15	+	20.0	64
7	2567	0.15	+	26.1	64	1615	0.08	+	17.0	65
8	1056	0.06	+	22.8	73	484	0.02	+	15.6	78
9	1367	0.08	+/0	22.8	67	541	0.03	+/0	14.4	100
10	560	0.03	0	23.3	65	465	0.02	0	17.8	84
Total collected	16,834					20,208				

Table 2(c). (cont.)

Trapping period[a]	13–14 Aug Number collected	Proportion of total	Moon	Air temp. (°C)	R.H. (%)
1	89	0.01	0	31.1	45
2	298	0.05	0	27.8	50
3	1150	0.18	0/+	23.9	56
4	900	0.14	+	22.2	78
5	487	0.07	+	21.1	57
6	765	0.12	+	18.9	60
7	592	0.09	+	16.7	64
8	1032	0.16	+	15.6	72
9	236	0.04	+/0	13.9	84
10	966	0.15	0	15.6	82
Total collected	6515				

collecting dates when moonlight was present, there was no significant cloud cover, except for 12–13 Aug and 16–17 Sep. On those dates, low clouds and fog covered the entire region during the late night and early morning hours. However, the evening of 12–13 Aug was moonless and, on 16–17 Sep, the moon set before the sky became overcast. The cloud cover during collection on those dates could have

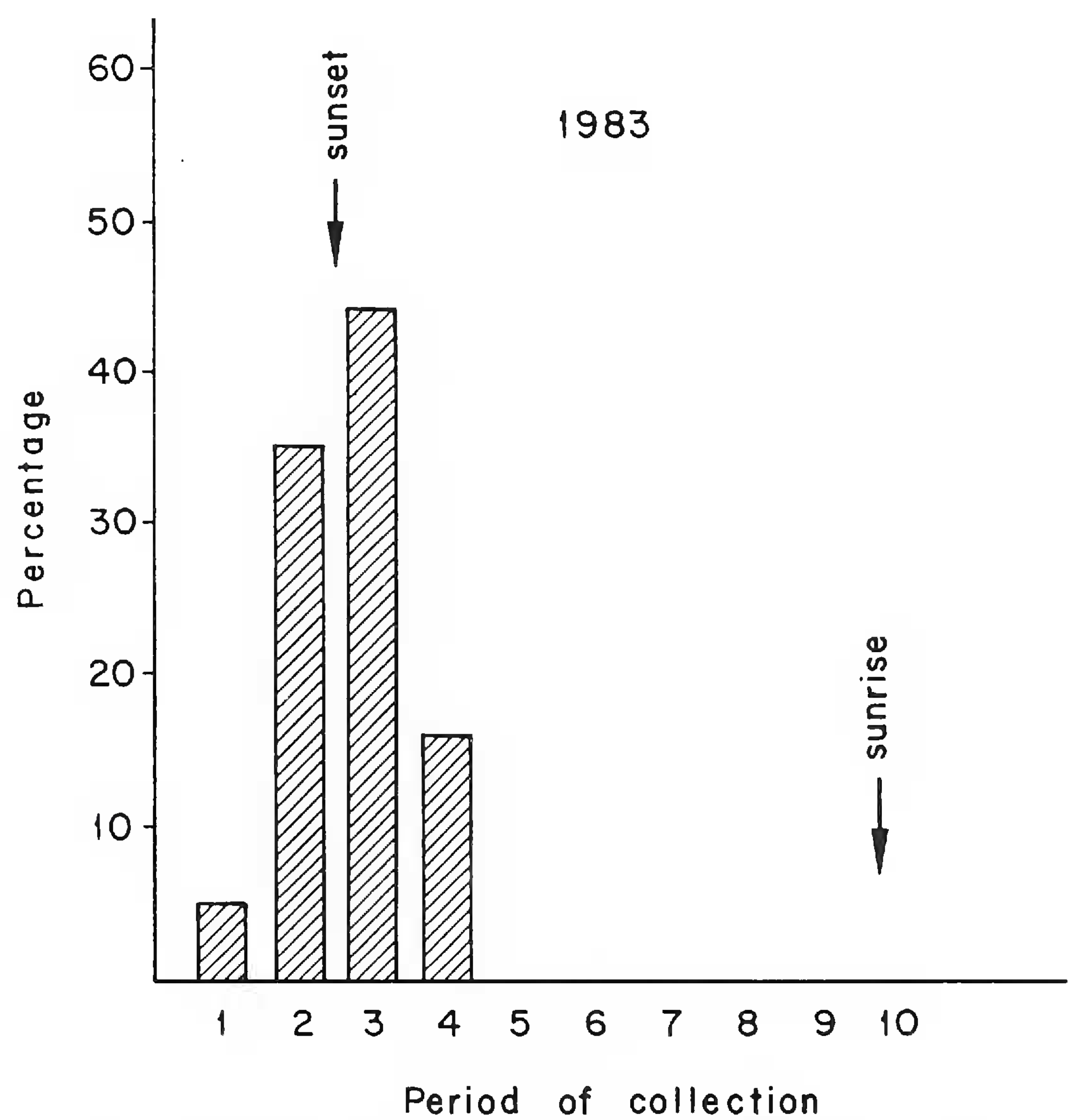

Figure 1. Percentage of female *Culicoides variipennis* collected during the various overnight trapping periods during a moonless night (September 9–10, 1983) in western Sonoma County.

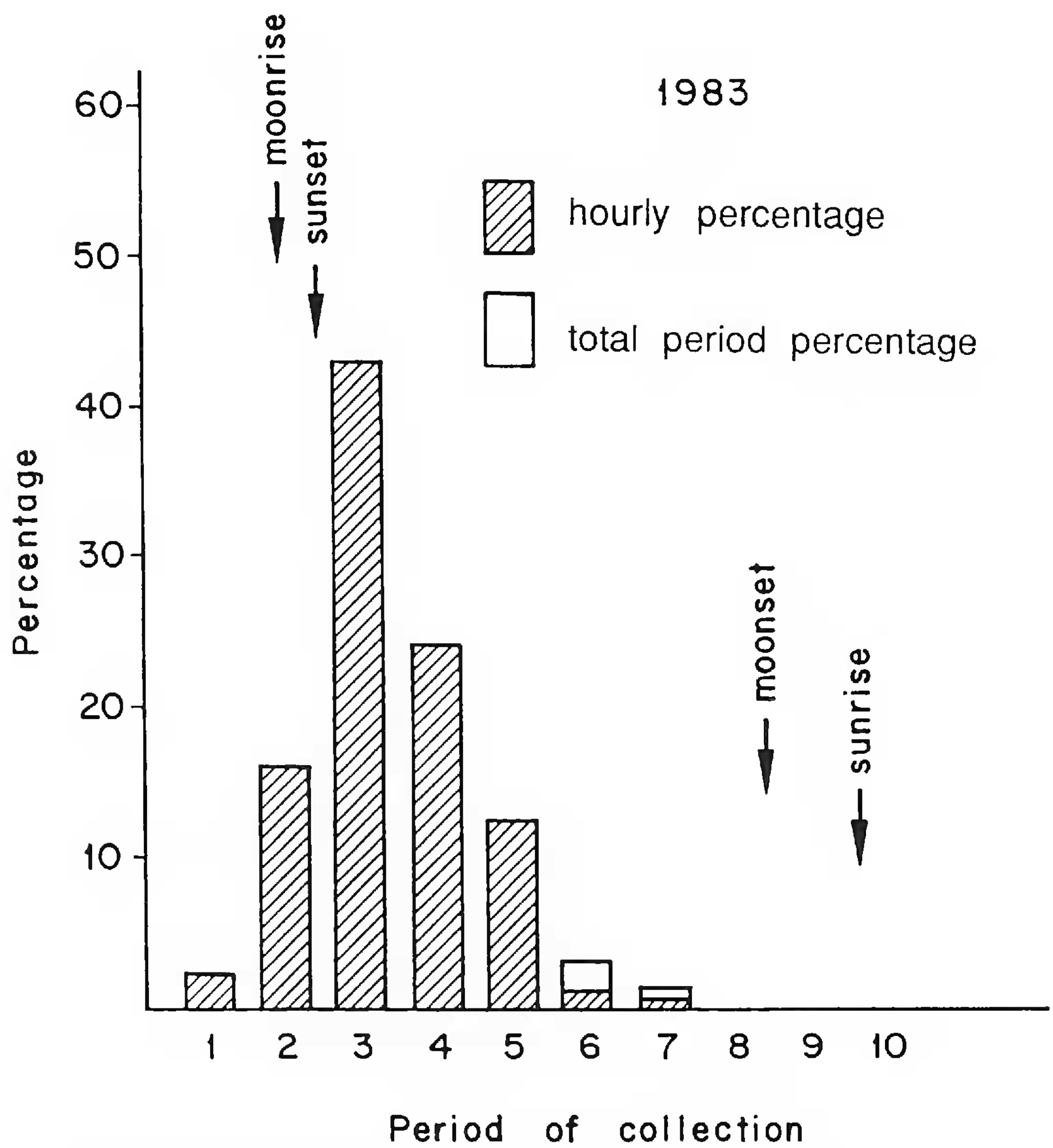

Figure 2. Percentage of female *Culicoides variipennis* collected during the various overnight trapping periods during a full moon night (September 19–20, 1983) in western Sonoma County.

been a factor preventing the air temperature from dropping below 10° C, resulting in some flight activity at dawn (Table 1).

Figures 1 and 2 show the pattern of flight activity for *C. variipennis* in the absence and presence of moonlight respectively, for two selected dates during 1983 (9–10 and 19–20 Sep). These data illustrate the positive influence of moonlight upon flight activity, with gnats being collected through period number seven on a moonlight night (19–20 Sep). Contrarily, in the absence of moonlight no gnats were collected after the fourth period on 9–10 Sep.

Trapping results for 1984 also reveal the positive influence of moonlight upon the flight activity of *C. variipennis* (Table 2). Although the peak activity in the study area was at dusk, high to moderate activity continued all night and through the early morning hours. Contrary to the Santa Rosa region, temperature was not as great a factor affecting the number and proportions of gnats collected in the San Joaquin Valley. Although temperatures below 17° C somewhat suppressed flight activity, overnight temperatures remained high enough to allow flight activity to continue throughout the entire collecting period on all trapping dates. Figure 3 shows the profile of the peaks of flight activity for this species in the San Joaquin Valley, for five collecting dates.

Although a different collecting method was used, the results presented here for flight activity in both years are in agreement with those of Nelson & Bellamy (1971) for *C. variipennis* in southern California. They found that flight activity,

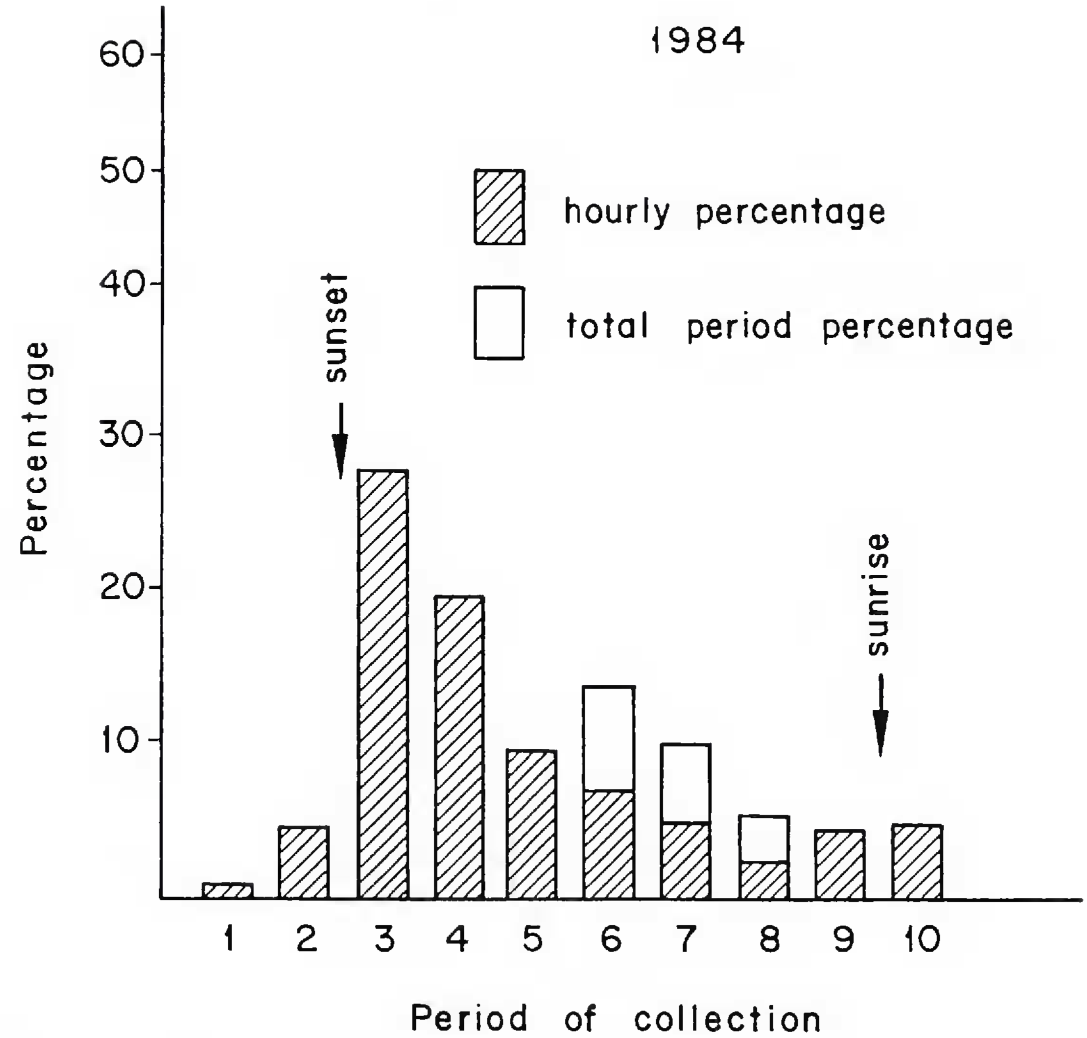

Figure 3. Percentage of female *Culicoides variipennis* collected during the various overnight trapping periods during full moon nights in the San Joaquin Valley of California (Stanislaus County). Results reflect the average of five full moon overnight collecting dates in July and August of 1984.

as measured by vehicle-mounted sweep net catches, generally was greater near sunset and sunrise and during moonlight hours than during darker periods of the night. They also concluded that the timing of occurrence of evening peaks appeared to be largely independent of evaporation rates and temperature, as long as these two factors remained within acceptable limits. This also appears to be true in North Coastal California (Sonoma County), where greater flight activity occurred in the presence of moonlight as long as temperatures were not below 7° C.

When Nelson & Bellamy (1971) also collected gnats using CO_2-baited traps they pointed out that the patterns of flight activity as measured by vehicle-mounted net catches did not always coincide closely with the results obtained with their CO_2-baited traps. Although they did not find a clear relationship between moonlight and attraction of *C. variipennis* to CO_2-baited traps, they reported an increase in light trap catches of *C. variipennis* during moonlight periods, as compared to darker periods of the night.

Barnard & Jones (1980) using a vehicle-mounted sweep net in Colorado also found a positive correlation between the presence of moonlight and increased flight activity of *C. variipennis,* as long as temperatures remained between 7° C and 35° C. They also concluded that the greatest period of flight activity occurred near sunset. Although climatic and topographic characteristics of northeastern Colorado differ from northern California, our results are in agreement with those of Barnard & Jones (1980) and Jones (1965), who collected some *C. variipennis* females feeding at a temperature as low as 13° C.

Lewis & Taylor (1965), who studied the flight pattern of many biting insect species, including Ceratopogonidae, concluded that light intensity was the major apparent factor controlling the timing of flight. Among the several species of *Culicoides* studied, several showed peaks of flight and biting activity near dusk and/or dawn. These authors suggested that the timing of these peaks was induced by changes in light intensity rather than by a specific value of light intensity. This appears to be true for *C. variipennis* as well, for the largest numbers were collected at dusk and, to a lesser extent, at dawn. These are periods when dramatic changes in light intensity occur.

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